DOCUMENT RESUME

ED 285 741 SE 048 329

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TITLE Storm Surges. Teacher Guide and Activity Book. OEAGLS Investigation No. 25.
INSTITUTION Ohio State Univ., Columbus. School of Natural Resources.
SPONS AGENCY National Oceanic and Atmospheric Administration (DOC), Rockville, Md. National Sea Grant Program.
PUB DATE 87
NOTE 29p.
AVAILABLE FROM Ohio Sea Grant Education Program, 29 West Woodruff Ave., Room 059, Columbus, OH 43210-1085 ($2.00 plus $1.00 postage).
PUB TYPE Guides - Classroom Use - Guides (For Teachers) (052) -- Guides - Classroom Use - Materials (For Learner) (051)

EDRS PRICE MF01/PC02 Plus Postage.
DESCRIPTORS Elementary Education; *Elementary School Science; Environmental Influences; *Marine Education; *Meteorology; *Science Activities; Science and Society; Science Education; *Science Experiments; Science Instruction; Teaching Methods; Water; Water Resources; Weather; Wind (Meteorology)
IDENTIFIERS *Lake Erie; Ohio Sea Grant Program; *Storms

ABSTRACT

This investigation is designed to help students understand storm surges on Lake Erie. Activity A includes experiments and discussions intended to help students understand what causes storm surges on Lake Erie. Activity B considers how storm surges affect water levels and, in turn, coastal areas. The student booklet contains questions, experiments, graphs, and a test for both major sections of the investigation. The accompanying teachers guide contains some additional background information and the answers to the questions in the student booklet. (TW)

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Storm Surges

by
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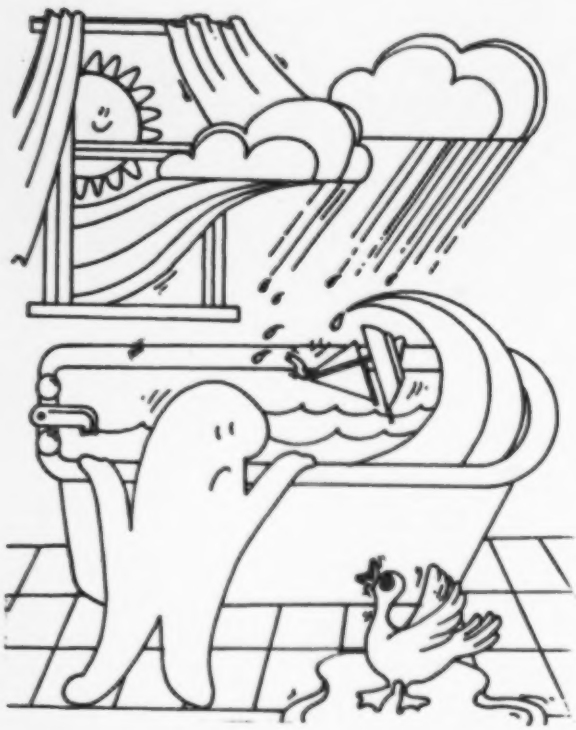

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Teacher Guide

OEAGLS–Oceanic Education Activities for Great Lakes Schools

SE 048 339

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OEAGLS Investigation #25

Completed December 1986

This instructional activity was prepared with the support of the National Oceanic and Atmospheric Administration, Sea Grant College Program Office, U.S. Department of Commerce, under Ohio Sea Grant Project #718716. Funding support was also provided by The Ohio State University's School of Natural Resources and College of Education. Any opinions, findings, conclusions or recommendations expressed herein are those of the authors, and do not necessarily reflect the views of NOAA or the University.

TEACHER GUIDE

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TEACHER GUIDE
STORM SURGES ON LAKE ERIE

by
John Keir and Victor J. Mayer

PREREQUISITE STUDENT BACKGROUND

1. Ability to interpret topographic maps.
2. Concept of low pressure systems (cyclones).
3. Ability to divide whole numbers.

MATERIALS

ACTIVITY A

1. Enough paint roller pans for each team of students. Some students may be able to bring one from home to share.
2. One roll of masking tape.
3. A water supply.
4. Paper towels to clean up spills.

TEACHER DEMONSTRATION

A ball that bounces easily. A golf ball, large super ball or basketball will do.

ACTIVITY B

1. Enough laminated maps of the Oregon Quadrangle, Ohio-Michigan 7.5 minute series (topographic) for each team of students. These can be obtained from the Ohio Department of Natural Resources at a cost of $2.50 each. You will have to laminate them yourself.

2. Enough sets of washable marker pens for each team of students. Each set should contain at least three colors of ink.

3. Paper towels and water to clean the maps after the activity is finished.

OBJECTIVES

These activities are designed to last three class periods. Students should work in teams of two. Activity A should be completed and discussed before proceeding to Activity B.

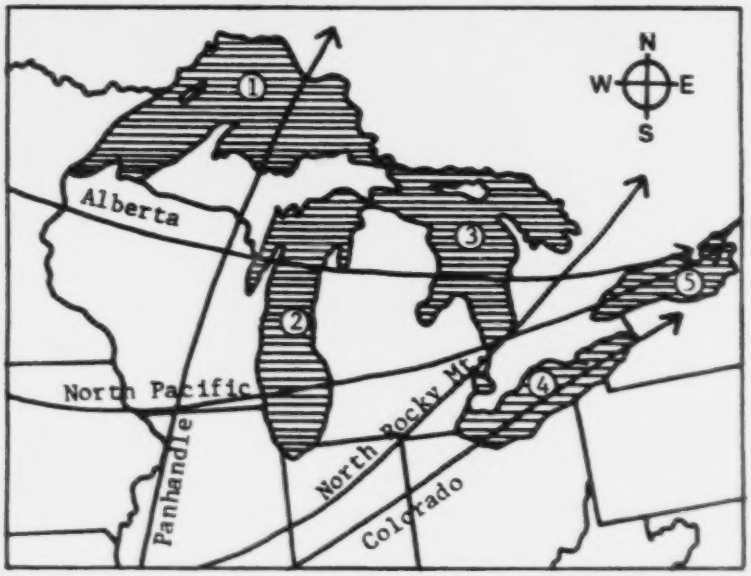
Note: Information to teachers is enclosed in boxes in this guide.

ACTIVITY A: WHAT CAUSES STORM SURGES ON LAKE ERIE?

Materials: Paint roller pan, water and masking tape.

A special type of water motion occurs on Lake Erie when a storm (low pressure center, or cyclone) moves across the lake. This motion is called a **storm surge**.

Lake Erie has several properties that cause it to have storm surges. One of them is that the lake is aligned with major storm tracks; the paths that cyclones (storms) take as they move across North America.



Key to Lakes:

1. Lake Superior
2. Lake Michigan
3. Lake Huron
4. Lake Erie
5. Lake Ontario

Figure 1. Storm tracks in the Great Lakes region.

PROCEDURE

Figure 1 is a map of the major storm tracks that affect the Great Lakes region.

1. What is the direction taken by most storms in the Great Lakes region?

T1. Most storms move southwest to northeast.

2. A. What would be the direction of a line drawn the length of Lake Erie through its middle? What would be the directions for Lakes Ontario, Huron, Michigan, and Superior?

   B. Which lakes are oriented in the same direction as that taken by most of the storms?

T2. A. Erie - W to E, Ontario - W to E, Michigan - S to N, Huron - N to S, Superior - W to E.
B. Lakes Erie, Ontario and Superior.

If a lake is oriented in the same direction as the path of storms it is more likely to be affected by storm surges. That is because the winds can blow across the water for a greater distance or **fetch**.

3. Which of the Great Lakes are most likely to be affected by storm surges because of orientation?

T3. Lakes Erie, Ontario and Superior.

The orientation of a lake is not the only factor that will affect the severity of storm surges. During a surge, the water is actually moved from one side of the lake to the other side. Therefore, the amount of water in a lake affects the severity of storm surges. The more water in a lake, the harder it is for a storm to move it, and the less water in a lake, the easier it is for a storm to move it. Table 1 lists the volumes of the Great Lakes.

Table 1. Volumes of the Great Lakes in cubic miles of water.

Superior	2935
Michigan	1180
Huron	849
Erie	116
Ontario	393

4. Which Great Lake would be the least likely to have a storm surge because of its volume of water? In other words, which lake would be hardest for a storm to move?

T4. Lake Superior.

5. Which Great Lake would be the most likely to have a storm surge because of its volume of water? In other words, which lake would be easiest for a storm to move?

T5. Lake Erie.

When a cyclone (storm) first moves over Lake Erie, the temperature drops and the wind changes direction. This disturbs the water in the lake and causes it to move in the same direction as the storm is moving. Since most cyclones move from the west towards the east, water is moved by the cyclone into the eastern end of the lake, which narrows quickly (see Figure 2). The water level in the eastern end of the lake is raised. This is called a **surge**.

The shape of the lake concentrates the effects of a surge at both ends. When the water level is raised at Buffalo it will be lowered at Toledo (see Figure 2 for the location of these cities). A surge can cause a difference of several feet in the water levels at each end of the lake.

On rare occasions, the wind blows out of the northeast. When this happens, a surge occurs at Toledo, which raises the water level there. After the cyclone leaves the lake, the piled up water moves toward the other end. The water sloshes from one end of the lake to the other a few times until the water level is returned to normal. This sloshing back and forth is called a **seiche**.

6. How is a seiche different from a surge?

T6. A surge is the piling up of the water by a storm. A seiche is the sloshing back and forth motion of the water.

Figure 2. Lake Erie.

TEACHER DEMONSTRATION

PROCEDURE: Note: You may have to repeat this several times so all students can see it up close.

a. Bounce the ball on the floor several times. Try to bounce the ball smoothly with the least amount of effort. Make your hand and the ball work together. Stop for a minute to let students answer question 7 on their answer sheet.

7. Describe what happened the first time the teacher bounced the ball.

T7. The teacher's hand and the ball worked together and the ball bounced higher and higher.

b. Now try to bounce the ball with your hand and the ball moving at different speeds. This may take a lot of effort to do. Try to bounce the ball with your hand moving down while the ball is coming up.

8. Describe what happened the second time the teacher bounced the ball.

T8. The teacher's hand and the ball did not work together.

9. When were the ball and the teacher's hand in resonance?

T9. The first time the teacher bounced the ball was an example of resonance.

Table 2. Average Depth of Great Lakes in feet.

Superior	487
Michigan	276
Huron	195
Erie	58
Ontario	283

The speed at which a surge or seiche moves across a lake depends on the depth of the lake (see Table 2). Surges and seiches move slower in deeper water. Surges and seiches move across Lake Erie at about 35 miles per hour.

10. Would surges and seiches move faster on any other Great Lake?

T10. No, because the other lakes are a different depth than Lake Erie, a surge or seiche would move at a different speed than 35 miles per hour.

If a cyclone moves across Lake Erie at 35 miles per hour it will be in resonance with the surge. This makes the surge bigger than normal, which means that the water level will change even more than if the storm were traveling at another speed.

Look at Figures 3 and 4. It is about 245 miles from Toledo to Buffalo. Find the speed of the storm by dividing the time it takes the storm to cross the lake into the distance from Toledo to Buffalo.

11. What is the speed of the storm in Figure 3?

T11. 35 miles per hour.

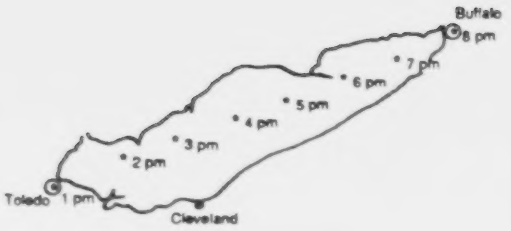


Figure 3. Cross-lake movement of cyclone center.
* - cyclone center and time.

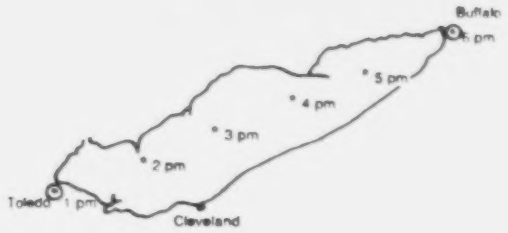


Figure 4. Cross-lake movement of cyclone center.
* - cyclone center and time.

12. What is the speed of the storm in Figure 4?

T12. 49 miles per hour.

13. Which storm would be in resonance with the surge it produced?

T13. The storm in Figure 3 would be in resonance.

The average speed of cyclones that cross Lake Erie is about 35 miles per hour. Lake Erie contains three different basins that have different depths (see Figure 5). The water is shallow near Toledo at the western end and deep near Buffalo at the eastern end.

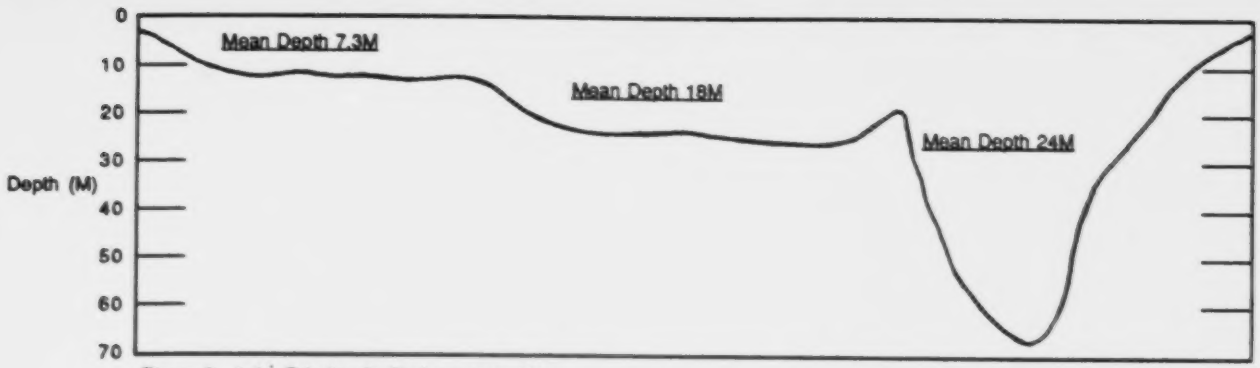


Figure 5. Lake Erie longitudinal cross section

In the following activity, you will use a paint roller pan to simulate Lake Erie and its different water depths.

14. Fill the paint roller pan with water until the water level is about 8 inches from the edge of the shallow end. This represents Lake Erie. Write "Toledo" on a piece of masking tape and put it at the edge of the water in the shallow end. Write "Buffalo" on another piece of tape and put it an inch above the water level at the deep end of the pan.

15. Hold the shallow end of the pan and gently tip it up an inch or so. This represents the water being moved toward the eastern end of the lake in a surge. Observe what happens to the lake near Toledo.

16. Describe what happened to the shallow (Toledo) end of the pan when the pan was tipped up.

T16. The water drained out of the shallow end.

17. Describe what happened to the shallow end of the pan when you set the end of the pan down.

T17. The water level sloshed back and forth until the water returned to a normal level.

18. What is this water motion called (in question 17)?

T18. This motion is called a seiche.

19. Hold the deep end of the pan and gently tip it up. Be careful not to spill water. This represents a surge moving toward Toledo.

20. Describe what happened to Toledo (in question 19).

T20. Toledo is flooded.

Buffalo, New York, is at the eastern end of Lake Erie and Toledo, Ohio, is at the western end. Both of these cities are affected by storm surges, but each city has different problems when one happens.

The water is deep at Buffalo and the shoreline rises quickly to high ground. This limits damages to the city itself caused by storm surges at the eastern end of the lake. However, boats and the docks they are tied to are damaged when the water level rapidly rises and falls, causing the boats to move around and bang against the docks.

Toledo has more problems to deal with. The water is shallow, and the land surrounding the western end of the lake is flat and lies at about the same elevation as the lake surface. When the water in Lake Erie is moved toward Buffalo in a large surge, a big part of Maumee Bay near Toledo can actually dry up. Boats that are tied to docks there will be sitting on the lake bottom when this happens. Commercial boating is disrupted and the water supply for some towns is cut off as well. When the water comes rushing back into the bay, the boats can be shoved under the docks and then lifted up, which damages or destroys both the boats and docks. In addition, when a surge is pushed toward Toledo,

the western end of the lake cannot hold all of the water that rushes into it. The water will spill out of the lake, flooding the land. Such floods have caused a lot of damage to property around Toledo.

21. List four problems caused by storm surges in the western part of Lake Erie.

T21. Commercial boating is disrupted, water supplies can be cut off, flooding, damage to boats and docks.

22. List three reasons that Lake Erie is affected by storm surges more than any other Great Lake.

T22. Orientation same as storm tracks, low volume makes it easier for storms to move the water, shallow depth, resonance.

ACTIVITY B: HOW DO STORM SURGES AFFECT WATER LEVEL?

Materials: Laminated maps of the Oregon Quadrangle, Ohio-Michigan 7.5 minute series (topographic), several colors of washable marker pens.

In April, 1979, a storm moving across Lake Erie caused a storm surge. The water level at Toledo dropped 7 feet below normal when the surge was at Buffalo. Water raised 5 feet above normal when the seiche returned water to Toledo.

1. Using the data on water levels above, determine the approximate low water mark in the lake and trace it on the map. This will represent the new, temporary Toledo shoreline when the surge was at Buffalo.

T1. The blue numbers on the map indicate depths below the mean lake elevation of 572 feet. Draw the line representing a water drop of 7 feet between the 6- and 8-foot depth readings in the upper right corner of the map. The new lake elevation will be 565 feet.

2. Use the scale at the bottom of the map to find out how far from shore the water moved. Write this information on your worksheet.

T2. Over 2 miles.

By studying records of storms and their effects on water level accumulated over many years, scientists have determined how often storms occur that cause a certain change in water level. This is called the **return frequency**. Table 3 lists the return frequencies for three different drops in water level.

Table 3. Return Frequency of Water Level Drawdown in Lake Erie's Western Basin Due to Storm Surges. Figures are given in feet.

frequency	distance below normal level
1.4 year	5
3 year	6
20 year	7

3. Look at Table 3. Use a different colored pen to trace the low water mark of the lake for the return frequency of 1.4 years.

T3. Draw a line connecting the 5-foot depth readings on the map. The elevation of the lake after a 5-foot drop in water level will be 568 feet.

4. Now trace the low water mark for the 3 year return frequency using another color.

5. Based on the lines you have drawn and the data in Table 3, what is the return frequency of the 1979 change in water level?

T5. 20 years.

Table 4. Return Frequency for Positive Storm Surges in Lake Erie's Western Basin. Figures are given in feet.

frequency	distance above normal level
3.3 year	3
8.3 year	4
33 year	5

6. Using data from Table 4, trace the high water mark for the 3.3 year return frequency surge at Toledo.

T6. The mean lake elevation is 572 feet. If the water is raised 3 feet above its normal level, the new elevation of the lake is 575 feet. Find the 575-foot contour line on the map and trace it.

7. Using different colored pens, trace the high water mark for the 8.3 and 33 year return frequencies.

T7. The new elevation for the 8.3 year return frequency is 576 feet. The new elevation for the 33 year return frequency is 577 feet. There are contour lines on the map representing 575 feet and 580 feet. You will have to estimate where your lines should be drawn between these two contour lines.

8. Using the scale at the bottom of the map, find out how far inland the floodwaters can come. Write this information on your worksheet.

T8. About 1 mile.

9. Look at Tables 3 and 4. Which problem would bother people living near Toledo the most often, high or low water levels?

T9. Low water levels would bother Toledo residents more often. Since storms usually track from the southwest toward the northeast, water is usually pushed out of the shallow end of the lake near Toledo, causing the water level to drop.

10. You are the Port Captain for the city of Toledo. Your job is to make sure commercial boats get safely into and out of the port. You have just been told that a storm tracking out of the northeast has caused the water level at Buffalo to drop by 6 feet. What will happen to the water level in Maumee Bay? A large ore freighter is approaching the port. What directions will you give to its captain? A coal freighter is just getting ready to leave port. What are your directions to its captain?

T10. These are open ended questions, so answers will vary. All students should understand that a water level drop at Buffalo means that the water level in Maumee Bay will go up. Discuss the different recommendations to the captains; students should give reasons for their recommendations.

Storm surges also occur on the oceans. Any storm can produce them. Hurricanes have been known to cause surges as high as 20 feet. To make matters worse there are giant waves on top of the surge which can cause huge amounts of damage when the surge reaches shore. They are the reason that people must leave low-lying areas near shore when a hurricane approaches. The people of Holland are spending nearly three billion dollars to build a series of dams to protect their country from storm surges coming from the North Sea and Atlantic Ocean. In 1985, several thousand people were killed by a storm surge that hit the coast of Bangladesh.

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EVALUATION ITEMS

1. Water sloshing back and forth across a lake is called a

   *a. seiche
   b. surge
   c. tide
   d. breaker

2. Water being piled up at one end of a lake by a storm is called a

   a. seiche
   *b. surge
   c. tide
   d. breaker

3. Most storms in the Great Lakes area move from

   *a. southwest to northeast
   b. north to south
   c. southeast to southwest
   d. south to north

4. Which of the following does not have an effect on the size of storm surges on the Great Lakes?

   a. lake volume
   b. lake alignment
   *c. cloud cover
   d. storm speed

5. Resonance occurs when the storm crossing the lake is

   a. moving faster than the surge
   b. moving slower than the surge
   *c. moving the same speed as the surge
   d. stopped

6. Which city is most likely to be damaged by storm surges?

   *a. Toledo
   b. Buffalo
   c. Detroit
   d. Duluth

7. Which Great Lake has the most problem with storm surges?

   a. Huron
   b. Michigan
   c. Ontario
   *d. Erie

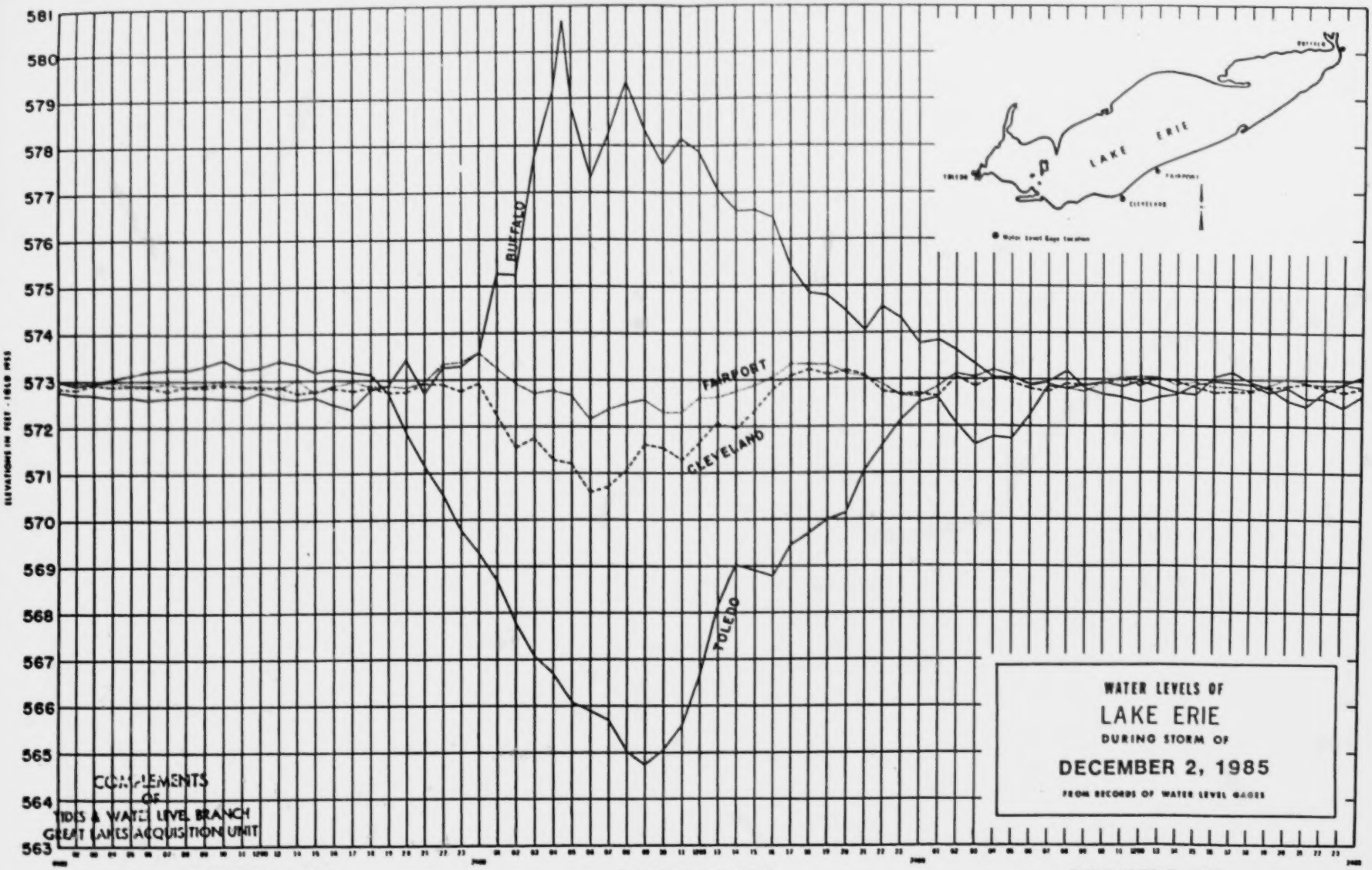
8. Storm surges can be caused by

   a. high pressure
   b. rising temperature
   *c. cyclones
   d. rain

EXTENDED BACKGROUND

The graph in this appendix displays the changes in water level in Lake Erie as a storm passed through on December 2, 1985. Notice that the water level at Toledo begins dropping at about 1800 hours, December 1, as the wind moves from the southwest and intensifies. The water at Buffalo does not begin to rise until about midnight, and then rises rather rapidly, producing the storm surge. It begins to drop at about 0430 hours at Buffalo and begins to rise at Toledo at about 0900 hours. Thus there appears to be about a 6-hour lag between events at the two ends of the lake. This would be about the time it would take for a storm traveling 35 miles per hour to pass over the lake. It took 28 hours for the effect of the storm to pass and for the lake to return to normal, so the period of the wave on the graph is about 14 hours (28 hours to travel down the lake and back, therefore 14 hours to travel one length of the lake). You might want to develop an activity around this graph for your more capable students.

NATIONAL OCEAN SERVICE, NOAA



DECEMBER 1, 1985 | DECEMBER 2, 1985 | DECEMBER 3, 1985

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 |
|---|---|---

ANSWER SHEET

ACTIVITY A

1. What direction do most storms take? _____

2. A. Erie _____, Ontario _____, Michigan _____, Huron _____,

   Superior _____.

   B. Which lakes are orientated in the same direction? _____

3. Which of the Great Lakes is most likely to be affected by storm surges because of its orientation? _____

   _____

4. Which lake would be hardest for a storm to move? _____

5. Which lake would be easiest to move? _____

6. What is the difference between a seiche and a surge? _____

   _____

7. What happened the first time the teacher bounced the ball? _____

   _____

8. What happened the second time the teacher bounced the ball?_____

   _____

9. When were the ball and the teacher's hand in resonance?_____

10. Would surges and seiches move faster on any other Great Lake? _____

11. Speed of storm in Figure 3 _____ Show your work.

12. Speed of storm in Figure 4 _____ Show your work.

13. Which storm would be in resonance with the surge it produced? _____

14. Label Toledo and Buffalo on the paint roller pan.

15. Observe what happens when you tip the pan.

16. What happened to the shallow end when you tipped it up? _____

    _____

17. What happened to the shallow end when you set the pan down? _____

_____

18. What is this water motion called ?_____

19. Observe what happens when you tip the pan.

20. Describe what happened in Toledo. _____

_____

21. List four problems caused by storm surges in the western part of Lake Erie. _____

_____

_____

_____

22. List three reasons Lake Erie is affected by storm surges more than any other Great Lake. _____

_____

_____

ACTIVITY B

1. Trace the new low water mark on your map.
2. How far did the water move? _____
3. Trace the low water mark for the 1.4 year return frequency on your map.
4. Trace the low water mark for the 3 year return frequency on your map.
5. What is the return frequency? _____
6. Trace the high water mark for the 3.3 year return frequency on your map.
7. Trace the high water marks for the 8.3 and 33 year return frequencies on your map.
8. How far inland can the floodwaters come? _____
9. Would high or low water levels bother people in Toledo?_____
10. What are your directions to its captain? _____

_____

_____

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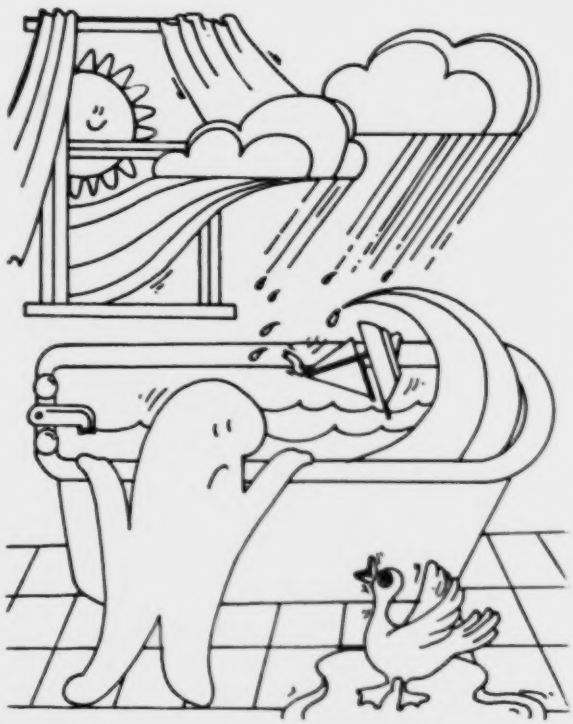

SE048 329

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STORM SURGES

by John Kier and Victor J. Mayer
Ohio Sea Grant Education Program

INTRODUCTION

Did you know that the water level on Lake Erie can change very quickly? Sometimes the lake will start to go down almost as if someone were draining the water away. Boats end up on the bottom of the lake, far from the water's edge. Pipes designed to draw water from the lake for use by some cities end up above the water's surface. Hours later the water level starts to rise rapidly. Boats are damaged as they bang against the docks. At other times the water can even overflow the lake shore, flooding large areas and causing extensive damage before the water level returns to normal.

These events happen on Lake Erie. They are caused by a storm surge. This activity will teach you what a storm surge is and why it is a problem only on Lake Erie.

OBJECTIVES: When you have completed these activities, you should be able to:

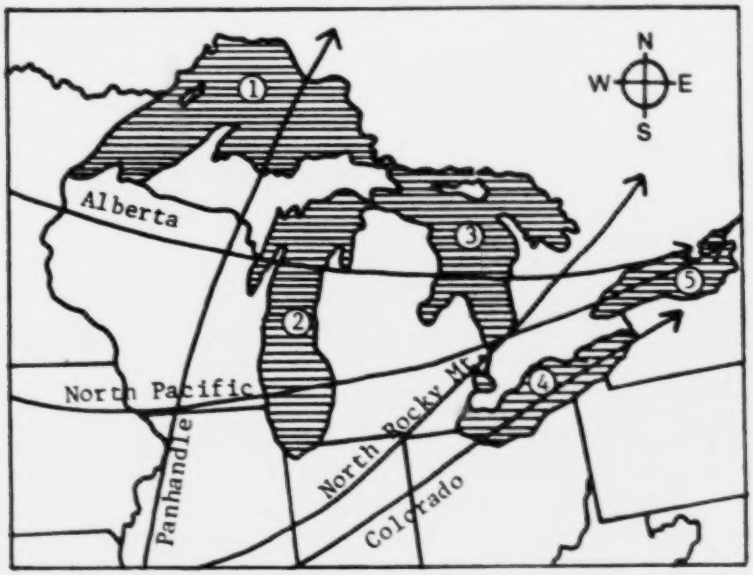
1. Describe the causes of storm surges on Lake Erie.
2. List the reasons that Lake Erie is affected by more severe storm surges than any of the other Great Lakes.
3. Describe the frequency of problems caused by storm surges at the western end of Lake Erie.
4. Describe the effects that a surge will have on the western end of Lake Erie.
5. Describe a seiche.
6. Describe resonance.

ACTIVITY A: WHAT CAUSES STORM SURGES ON LAKE ERIE?

Materials: Paint roller pan, water and masking tape.

A special type of water motion occurs on Lake Erie when a storm (low presure center, or cyclone) moves across the lake. This motion is called a storm surge.

Lake Erie has several properties that cause it to have storm surges. One of them is that the lake is aligned with major storm tracks; the paths that cyclones (storms) take as they move across North America.



Key to Lakes:

1. Lake Superior
2. Lake Michigan
3. Lake Huron
4. Lake Erie
5. Lake Ontario

Figure 1. Storm tracks in the Great Lakes region.

PROCEDURE

Figure 1 is a map of the major storm tracks that affect the Great Lakes region.

1. What is the direction taken by most storms in the Great Lakes region?

2. A. What would be the direction of a line drawn the length of Lake Erie through its middle? Use the same choices as in question 1. Do the same for Lakes Ontario, Michigan, Huron and Superior.

   B. Which lakes are oriented in the same direction as that taken by most of the storms?

If a lake is oriented in the same direction as the path of storms it is more likely to be affected by storm surges. That is because the winds can blow across the water for a greater distance or fetch.

3. Which of the Great Lakes is most likely to be affected by storm surges because of orientation?

Orientation of a lake is not the only factor. During a surge, the water is actually moved from one side of the lake to the other side. Therefore, the amount of water in a lake is a factor in storm surges. The more water in a lake, the harder it is for a storm to move it, and the less water in a lake, the easier it is for a storm to move it. Table 1 lists the volumes of the Great Lakes.

Table 1. Volumes of the Great Lakes in cubic miles of water.

Superior	2935
Michigan	1180
Huron	849
Erie	116
Ontario	393

4. Which Great Lake would be the least likely to have a storm surge because of its volume of water? In other words, which lake would be hardest for a storm to move?

5. Which Great Lake would be the most likely to have a storm surge because of its volume of water? In other words, which lake would be easiest for a storm to move?

When a cyclone (storm) first moves over Lake Erie, the temperature drops and the wind changes direction. This disturbs the water in the lake and causes it to move in the same direction as the storm is moving. Since most cyclones move from the west towards the east, water is moved by the cyclone into the eastern end of the lake, which narrows quickly

(see Figure 2). The water level in the eastern end of the lake is raised. This is called a surge. The shape of the lake concentrates the effects of a surge at both ends. When the water level is raised at Buffalo it will be lowered at Toledo (see Figure 2 for the location of these cities). A surge can cause a difference in water level of several feet between both ends.

On rare occasions, the wind blows out of the northeast. When this happens, a surge occurs at Toledo, which raises the water level there. After the cyclone leaves the lake, the piled up water moves toward the other end. The water sloshes from one end of the lake to the other a few times until the water level is returned to normal. This sloshing back and forth is called a seiche.

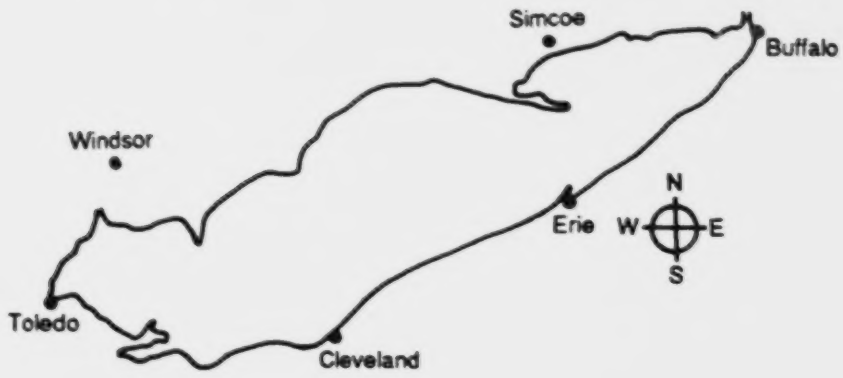


Figure 2. Lake Erie.

6. How is a seiche different from a surge?

When two things work together they are said to be in resonance. Watch your teacher bounce a ball a couple of different ways.

7. Describe what happened the first time the teacher bounced the ball.

8. Describe what happened the second time the teacher bounced the ball.

9. When were the ball and the teacher's hand in resonance?

The speed at which a surge or seiche moves across a lake depends on the depth of the lake (see Table 2). Surges and seiches move slower in deeper water. Surges and seiches move across Lake Erie at about 35 miles per hour.

10. Would surges and seiches move faster on any other Great Lake?

If a cyclone moves across Lake Erie at 35 miles per hour it will be in resonance with the surge. This makes the surge bigger than normal, which means that the water level will change even more than if the storm were traveling at another speed.

Table 2. Average Depth of Great Lakes in feet.

Superior	487
Michigan	276
Huron	195
Erie	58
Ontario	283

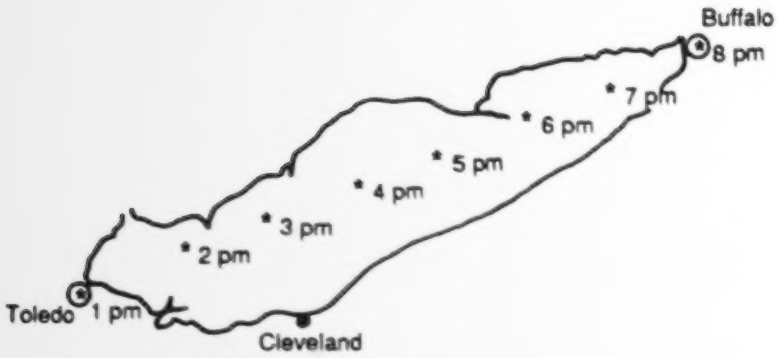


Figure 3. Cross-lake movement of cyclone center.
* - cyclone center and time.

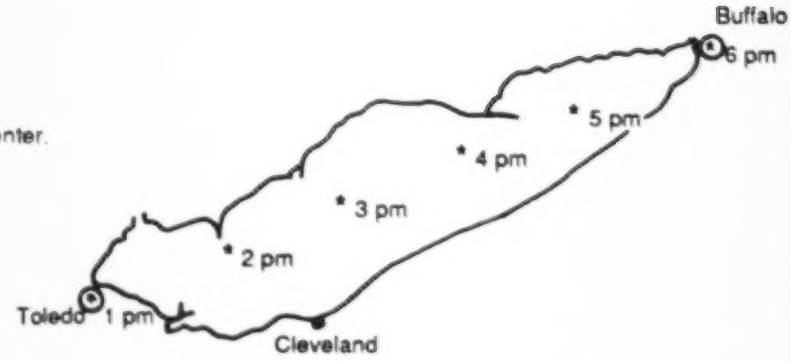


Figure 4. Cross-lake movement of cyclone center.
* - cyclone center and time.

Look at Figures 3 and 4. It is about 245 miles from Toledo to Buffalo. Find the speed of the storm by dividing the time it takes the storm to cross the lake into the distance from Toledo to Buffalo.

11. What is the speed of the storm in Figure 3?

12. What is the speed of the storm in Figure 4?

13. Which storm would be in resonance with the surge it produced?

The average speed of cyclones that cross Lake Erie is about 35 miles per hour. Lake Erie contains three different basins that have different depths (see Figure 5). The water is shallow near Toledo at the western end and deep near Buffalo at the eastern end.

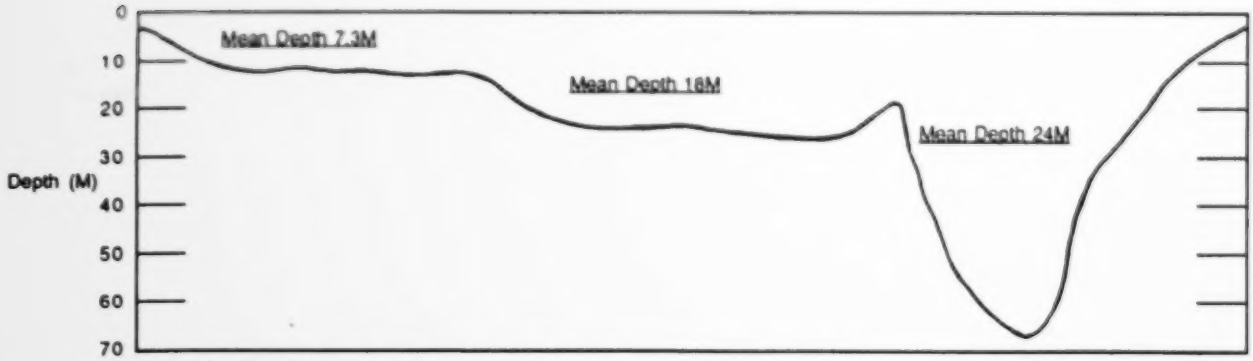


Figure 5. Lake Erie longitudinal cross section

In the following activity, you will use a paint roller pan to simulate Lake Erie and its different water depths.

14. Fill the paint roller pan with water until the water level is about 8 inches from the edge of the shallow end. This represents Lake Erie. Write "Toledo" on a piece of masking tape and put it at the edge of the water in the shallow end. Write "Buffalo" on another piece of tape and put it an inch above the water level at the deep end of the pan.

15. Hold the shallow end of the pan and gently tip it up an inch or so. This represents the water being moved toward the eastern end of the lake in a surge. Observe what happens to the lake near Toledo.

16. Describe what happened to the shallow (Toledo) end of the pan when the pan was tipped up.

17. Describe what happened to the shallow end of the pan when you set the end of the pan down.

18. What is this water motion called (in question 17)?

19. Hold the deep end of the pan and gently tip it up. Be careful not to spill water. This represents a surge moving toward Toledo.

20. Describe what happened to Toledo (in 19).

Buffalo, New York, is at the eastern end of Lake Erie and Toledo, Ohio, is at the western end. Both of these cities are affected by storm surges, but each city has different problems when one happens.

The water is deep at Buffalo and the shoreline rises quickly to high ground. This limits problems caused by storm surges at the eastern end and to the lake itself. However, boats and the docks they are tied to are damaged when the water level rapidly rises and falls, causing the boats to move around and bang against the docks.

Toledo has more problems to deal with. The water is shallow, and the land surrounding the western end of the lake is flat-lying and not of much higher elevation than the lake. When the water in Lake Erie is moved toward Buffalo in a large surge, a big part of Maumee Bay near Toledo can actually dry up. Boats that are tied to docks there will be sitting on the lake bottom when this happens. Commercial boating is disrupted and the water supply for some towns is cut off as well. When the water comes rushing back into the bay, the boats can be shoved under the docks and then lifted up, which damages or destroys both the boats and docks. In addition, when a surge is pushed toward Toledo, the western end of the lake cannot hold all of the water that rushes into it. The water will spill out of the lake, flooding the land. Such floods have caused a lot of damage to property around Toledo.

21. List four problems caused by storm surges in the western part of Lake Erie.

22. List three reasons that Lake Erie is affected by storm surges more than any other Great Lake.

ACTIVITY B: WATER LEVEL CHANGES CAUSED BY STORM SURGES ON LAKE ERIE

Materials: Laminated maps of the Oregon Quadrangle, Ohio-Michigan 7.5 minute series (topographic), several colors of washable marker pens.

In April, 1979, a storm moving across Lake Erie caused a storm surge. The water level at Toledo dropped 7 feet below normal when the surge was at Buffalo. Water raised 5 feet above normal when the seiche returned water to Toledo.

1. Using the data on water levels above, determine the approximate low water mark in the lake and trace it on the map. This will represent the new, temporary Toledo shoreline when the surge was at Buffalo.

2. Use the scale at the bottom of the map to find out how far from shore the water moved. Write this information on your worksheet.

By using records of storms and their effects on water level accumulated over many years, scientists have determined how often storms occur that cause a certain change in lake level. For example, every 3 years one will occur that will cause the water level to drop 6 feet.

3. Using the data in Table 3, trace the low water mark of the lake on the map for the expected 1.4 year frequency. Return frequency means how often a surge of this size is expected to happen, based on past records.

Table 3. Return Frequency of Water Level Drawdown in Lake Erie's Western Basin Due to Storm Surges. Figures are given in feet.

frequency	distance below normal level
1.4 year	5
3 year	6
20 year	7

4. Using different colored pens, trace the low water mark for the 3 and 20 year return frequencies.

5. Looking at the map, what would you say the return frequency was for the 1979 surge that you marked on the map before?

6. Using data from Table 4, trace the high water mark for the 3.3 year return frequency surge at Toledo.

Table 4. Return Frequency for Positive Storm Surges in Lake Erie's Western Basin. Figures are given in feet.

frequency	distance above normal level
3.3 year	3
8.3 year	4
33 year	5

7. Using different colored pens, trace the high water mark for the 8.3 and 33 year return frequencies.

8. Using the scale at the bottom of the map, find out how far inland the floodwaters can come. Write this information on your worksheet.

9. Look at tables 3 and 4. Which problem would bother people living near Toledo the most often, high or low water levels?

10. You are the Port Captain for the city of Toledo. Your job is to make sure commercial boats get safely into and out of the port. You have just been told that a storm surge with a water level drop of 6 feet has hit Buffalo. You know that the water level in Maumee Bay will go up several feet soon. A large ore freighter is approaching the port. What directions will you give to its captain? A coal freighter is just getting ready to leave port. What are your directions to its captain?

Storm surges also occur on the oceans. Any storm can produce them. Hurricanes have been known to cause surges as high as 20 feet. To make matters worse there are giant waves on top of the surge which can cause huge amounts of damage when the surge reaches shore. They are the reason that people must leave low-lying areas near shore when a hurricane approaches. The people of Holland are spending nearly three billion dollars to build a series of dams to protect their country from storm surges coming from the North Sea and Atlantic Ocean. In 1985, several thousand people were killed by a storm surge that hit the coast of Bangladesh.

ANSWER SHEET

ACTIVITY A

1. What direction do most storms take? _____

2. A. Erie _____, Ontario _____, Michigan _____, Huron _____,

   Superior _____.

   B. Which lakes are orientated in the same direction? _____

3. Which of the Great Lakes is most likely to be affected by storm surges because of orientation _____

   _____

4. Which lake would be hardest for a storm to move? _____

5. Which lake would be easiest to move? _____

6. What is the difference between a seiche and a surge? _____

   _____

7. What happened the first time the teacher bounced the ball? _____

   _____

8. What happened the second time the teacher bounced the ball?_____

   _____

9. When were the ball and the teacher's hand in resonance?_____

10. Would surges and seiches move faster on any other Great Lake? _____

11. Speed of storm in Figure 3 _____ Show your work.

12. Speed of storm in Figure 4 _____ Show your work.

13. Which storm would be in resonance with the surge it produced? _____

14. No answer is needed.

15. No answer is needed.

16. What happened to the shallow end when you tipped it up? _____

    _____

17. What happened to the shallow end when you set the pan down? _____

_____

18. What is this water motion called ?_____

19. No answer is needed.

20. Describe what happened in Toledo. _____

_____

21. List four problems caused by storm surges in the western part of Lake Erie. _____

_____

_____

_____

22. List three reasons Lake Erie is affected by storm surges more than any other Great Lake. _____

_____

_____

ACTIVITY B

1. No answer is needed.

2. How far did the water move? _____

3. No answer is needed.

4. No answer is needed.

5. What is the return frequency? _____

6. No answer is needed.

7. No answer is needed.

8. How far inland can the floodwaters come? _____

9. Would high or low water levels bother people in Toledo?_____

10. What are your directions to its captain? _____

_____

_____

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